# DETERMINING AEROSOL RADIATIVE FORCING AT ARM SITES:

# A CHALLENGE FOR

# ASP AND ARM

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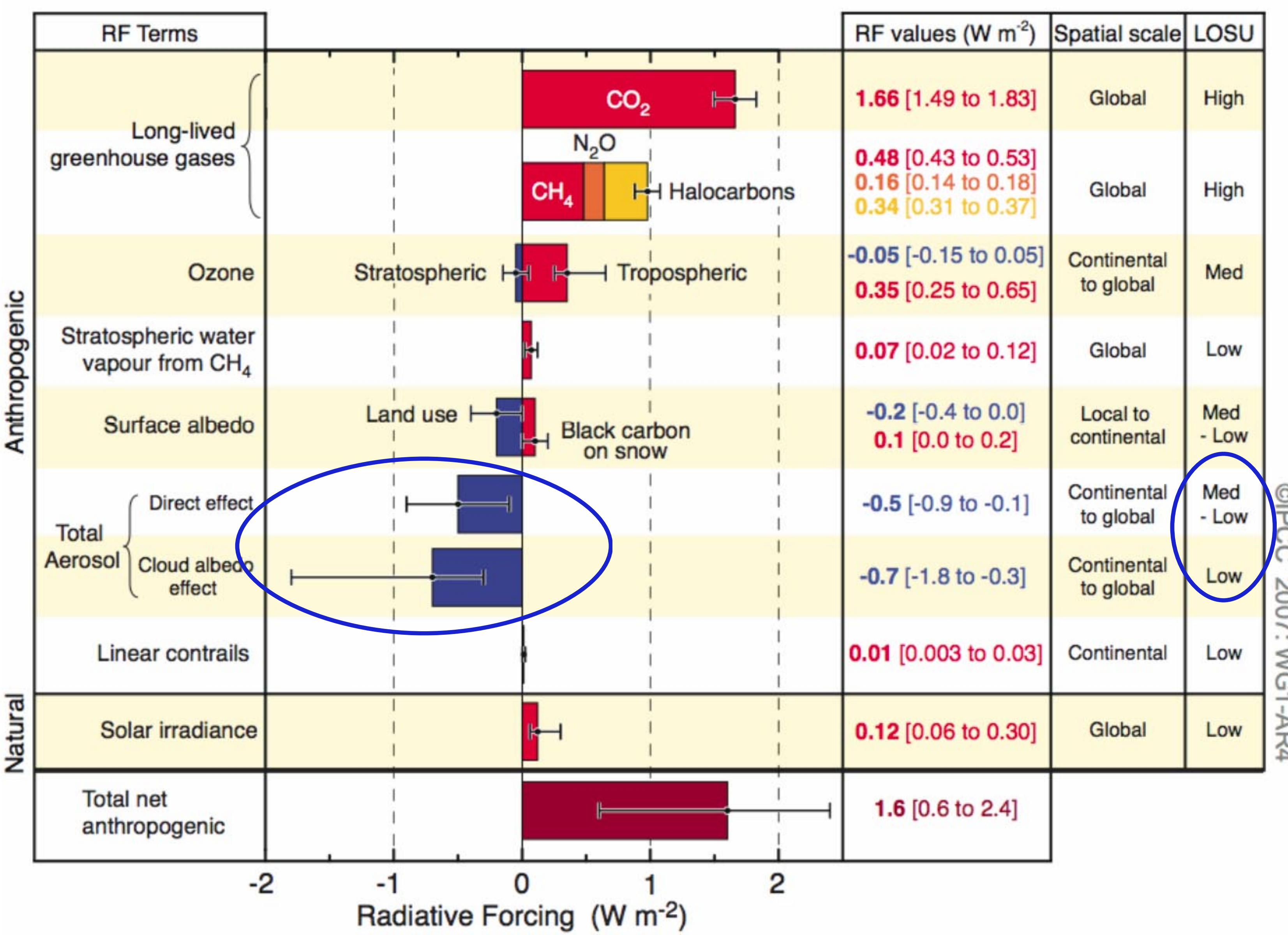
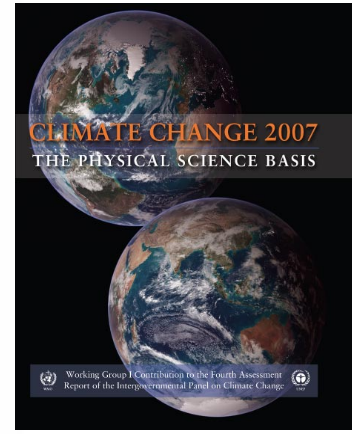
# GLOBAL-MEAN RADIATIVE FORCINGS (RF)

Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)




LOSU denotes level of scientific understanding.

# AEROSOL RADIATIVE FORCING DEFINITION

## From CCSP SAP 2.3

Net energy flux (downwelling minus upwelling) ***difference*** between an ***initial*** and a ***perturbed*** aerosol loading state, at a specified level in the atmosphere.

There are a number of ***subtleties*** associated with this definition:

The ***initial state*** against which aerosol forcing is assessed must be specified.

A distinction must be made between

***Total aerosol RF*** – Initial state is complete absence of aerosols; and

***Anthropogenic aerosol RF*** - Initial state is natural (preindustrial) aerosol.

In general, total aerosol RF and anthropogenic aerosol RF include energy associated with both the ***shortwave*** (solar) and the ***longwave*** (primarily planetary thermal infrared) radiative components.

. . .

# AEROSOL RADIATIVE FORCING DEFINITION *cont'd*

Aerosol direct RF can be evaluated under ***cloud-free conditions*** or ***"all-sky"*** conditions.

Cloud-free direct aerosol forcing is ***more easily and more accurately measured or calculated***.

Cloud-free direct aerosol forcing generally exceeds all-sky forcing because clouds mask the aerosol contribution to the scattered light.

Indirect aerosol RF must be evaluated for all-sky conditions.

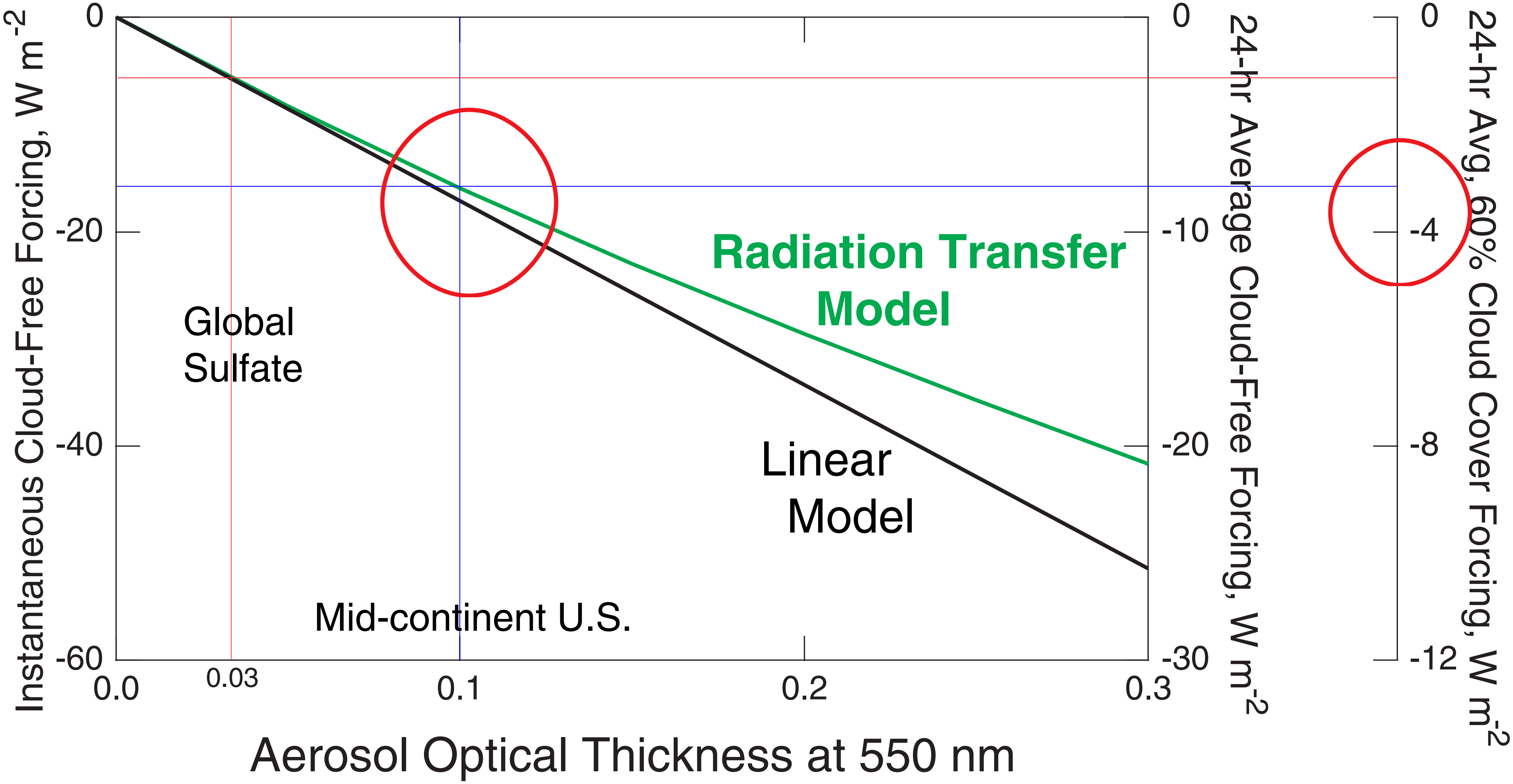
Aerosol RF can be evaluated ***instantaneously***, or ***daily averaged*** (24-hour), or some other time period.

Measurements generally provide instantaneous values.

Models usually consider aerosol RF as a daily average quantity.

# ESTIMATES OF AEROSOL DIRECT FORCING

By linear model and by radiation transfer modeling

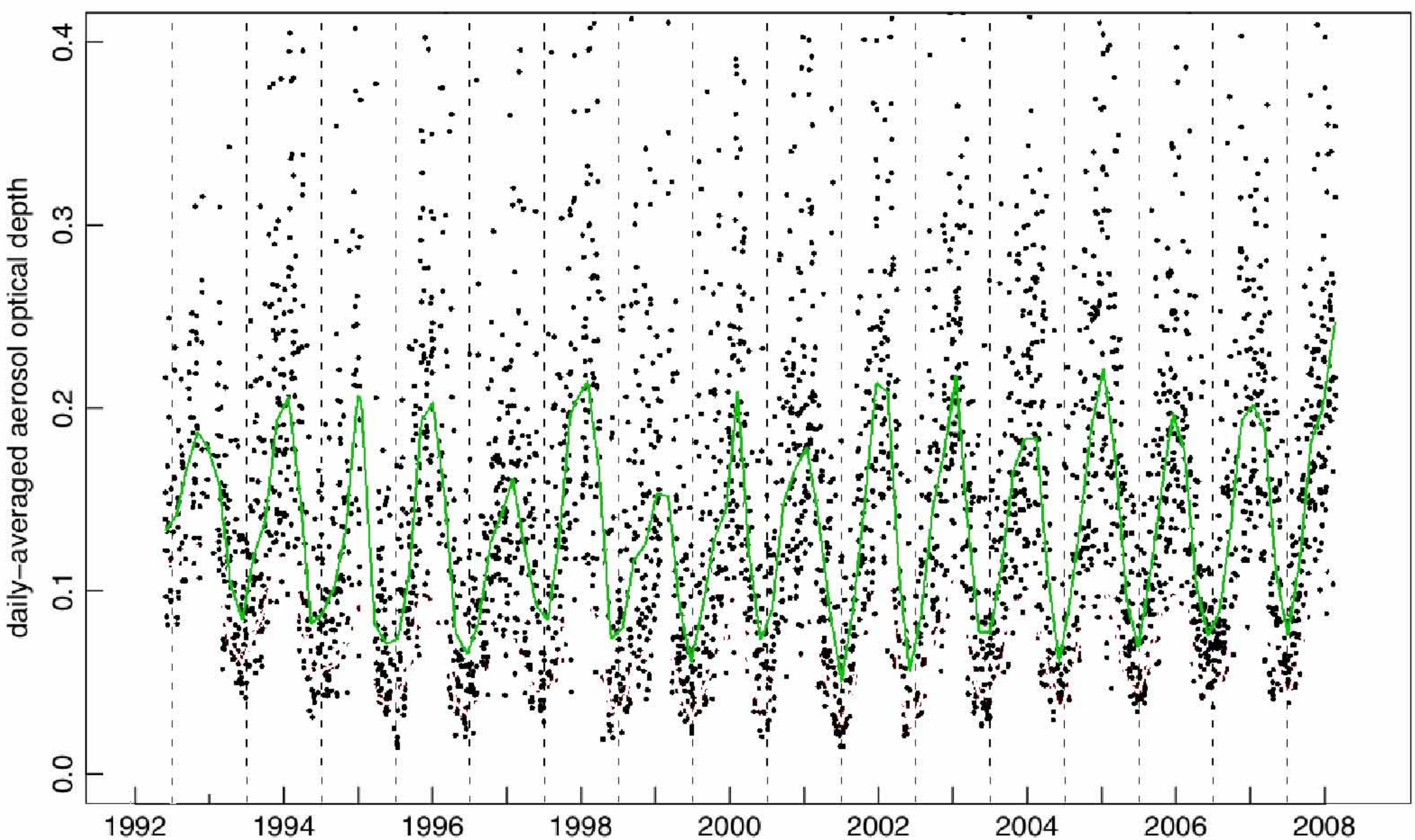



***Global average sulfate*** optical thickness is 0.03: ***1 W m$^{-2}$ cooling.***

In ***continental U. S.*** typical aerosol optical thickness is 0.1: ***3 W m$^{-2}$ cooling.***

# AEROSOL OPTICAL DEPTH AT ARM SGP

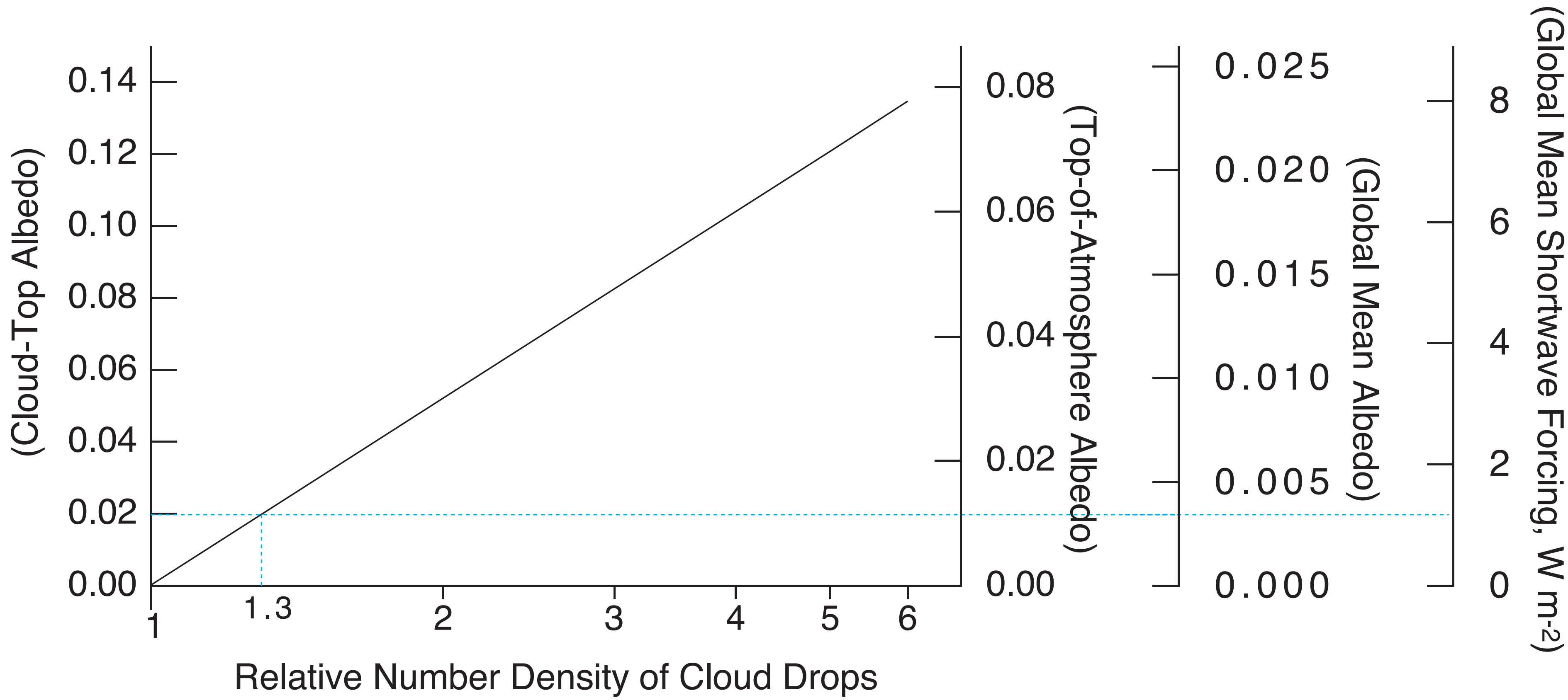
Fifteen years of daily average 500 nm AOD in North Central Oklahoma




*J. Michalsky et al., in prepration*

Green curve is LOWESS (locally weighted scatterplot smoothing) fit.

# SENSITIVITY OF ALBEDO AND FORCING TO CLOUD DROP CONCENTRATION




*Schwartz and Slingo (1996)*

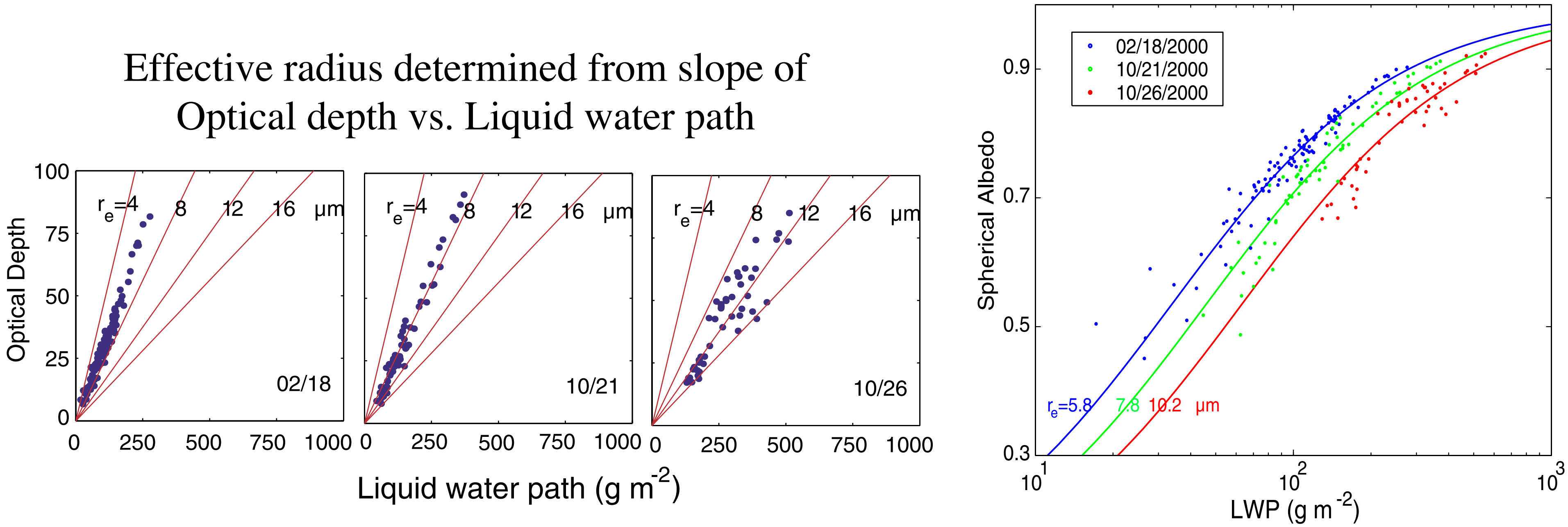
*Indirect forcing is highly sensitive to perturbations in cloud drop concentration.*

*A 30% increase in cloud drop concentration results in a forcing of ~1 W $m^{-2}$.*

# CLOUD ALBEDO AND FORCING CALCULATED FROM MEASURED EFFECTIVE RADIUS AND LIQUID WATER PATH

## North Central Oklahoma

Effective radius determined from slope of Optical depth vs. Liquid water path



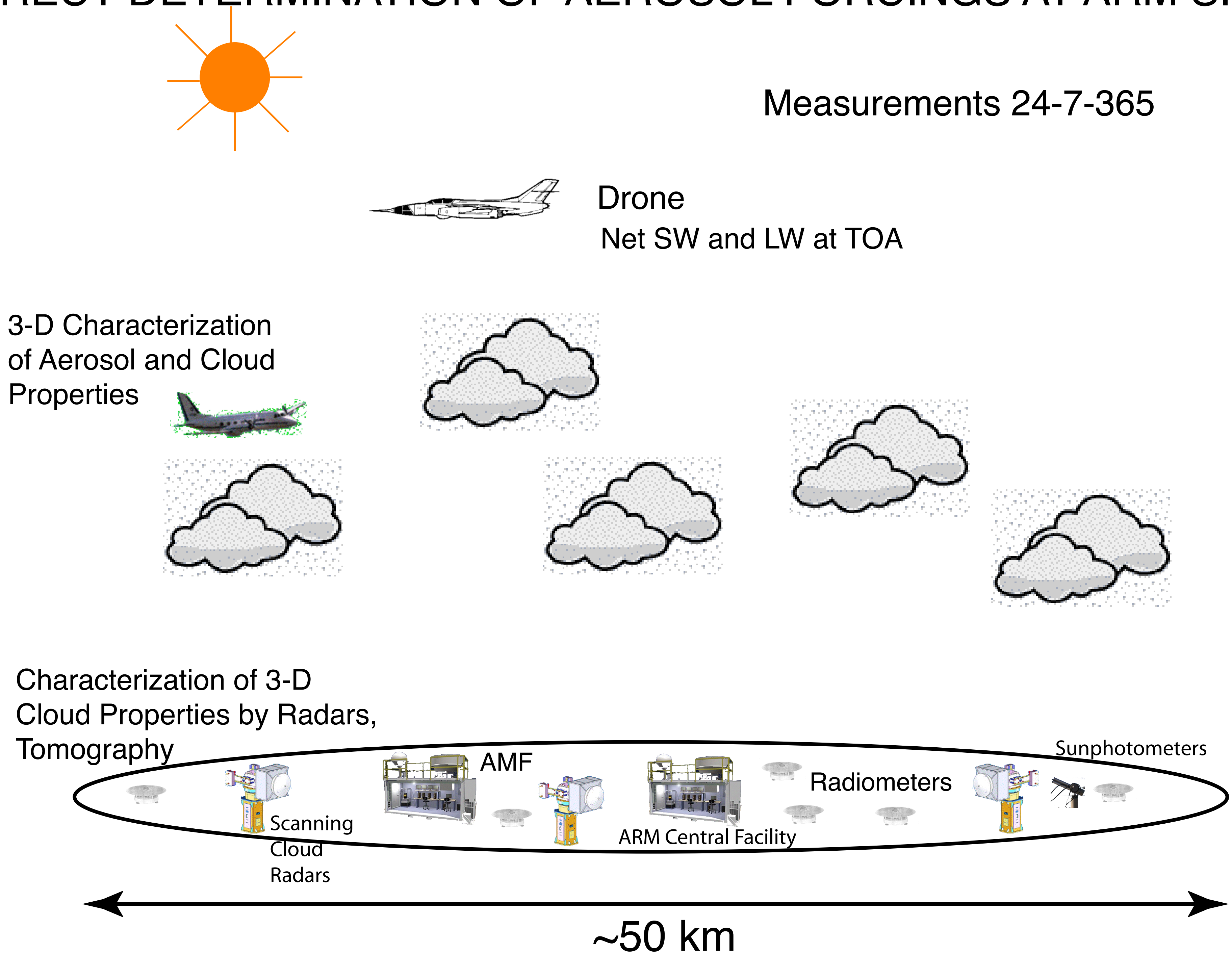

Cloud albedo is calculated for observed data and for average effective radius for each day. Forcing is calculated for indicated conditions relative to October 26.

Radiative forcing for solar zenith angle 60° and liquid water path 100 g m$^{-2}$

| Date, 2000 | Effective radius $r_e$, μm | Optical Depth | Net flux at TOA W m$^{-2}$ | Forcing relative to 10/26, W m$^{-2}$ |
|---|---|---|---|---|
| 10/26 | 10.2 | 15.1 | 293 | — |
| 10/21 | 7.8 | 20.8 | 266 | 27 |
| 02/18 | 5.8 | 28.3 | 240 | 53 |

*Kim, Schwartz, Miller, and Min, JGR, 2003*

# DIRECT DETERMINATION OF AEROSOL FORCINGS AT ARM SITES



# DIMENSIONS OF AEROSOL RADIATIVE FORCING

At least ***six dimensions*** to definition of aerosol RF:

| | |
|---|---|
| Direct | Indirect |
| Cloud-free | All-sky |
| Top-of-Atmosphere | Surface |
| Total aerosol RF | Anthropogenic aerosol RF |
| Shortwave | Longwave |
| Instantaneous | 24-hr to annual average |

At least ***64*** aerosol radiative forcing quantities.

Each aerosol RF is a ***difference*** between two fluxes: perturbed aerosol minus initial aerosol.

# DIMENSIONS OF AEROSOL RADIATIVE FORCING

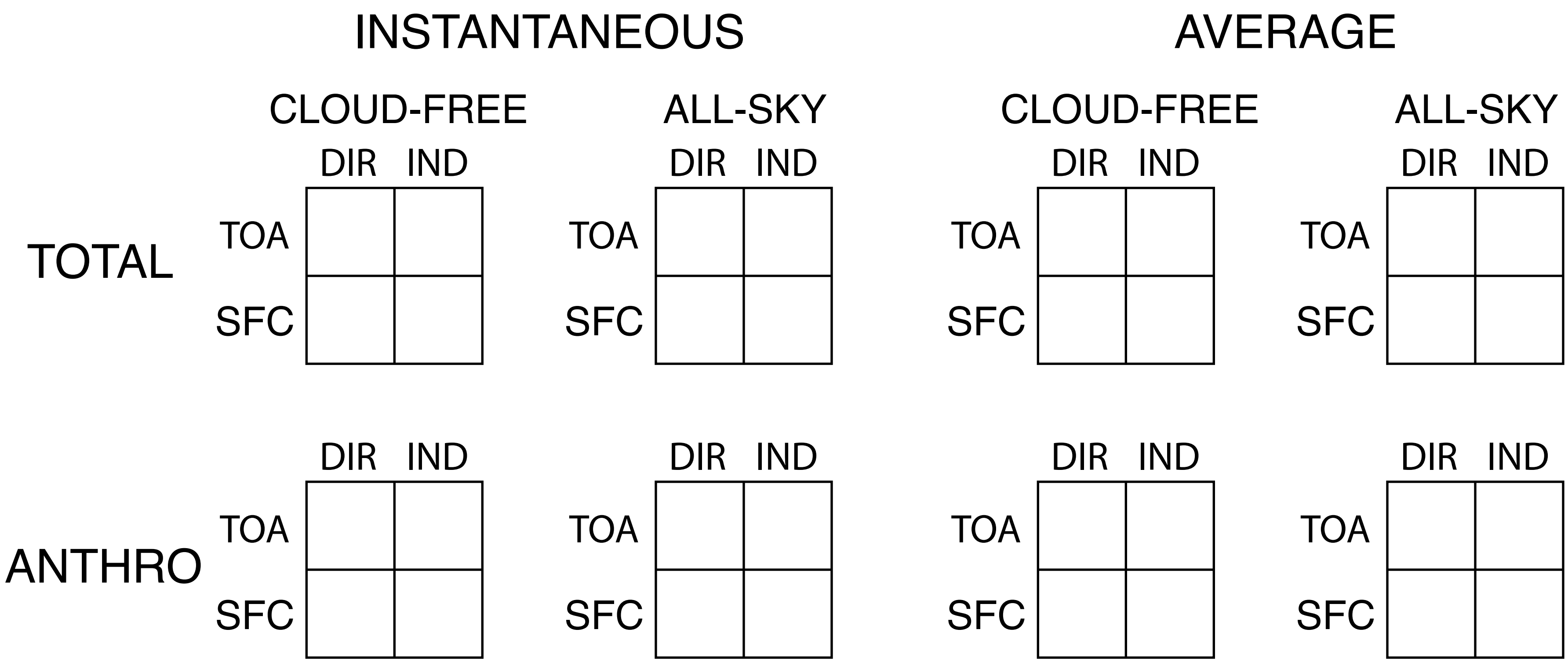
At least ***seven dimensions*** to definition of aerosol RF:

| | |
|---|---|
| Direct | Indirect |
| Cloud-free | All-sky |
| Top-of-Atmosphere | Surface |
| Total aerosol | Anthropogenic aerosol |
| Shortwave | Longwave |
| Instantaneous | 24-hr to annual average |
| Local | Global |

At least $2^7$ = ***128*** aerosol radiative forcing quantities.

Each aerosol RF is a ***difference*** between two fluxes: perturbed aerosol minus initial aerosol.

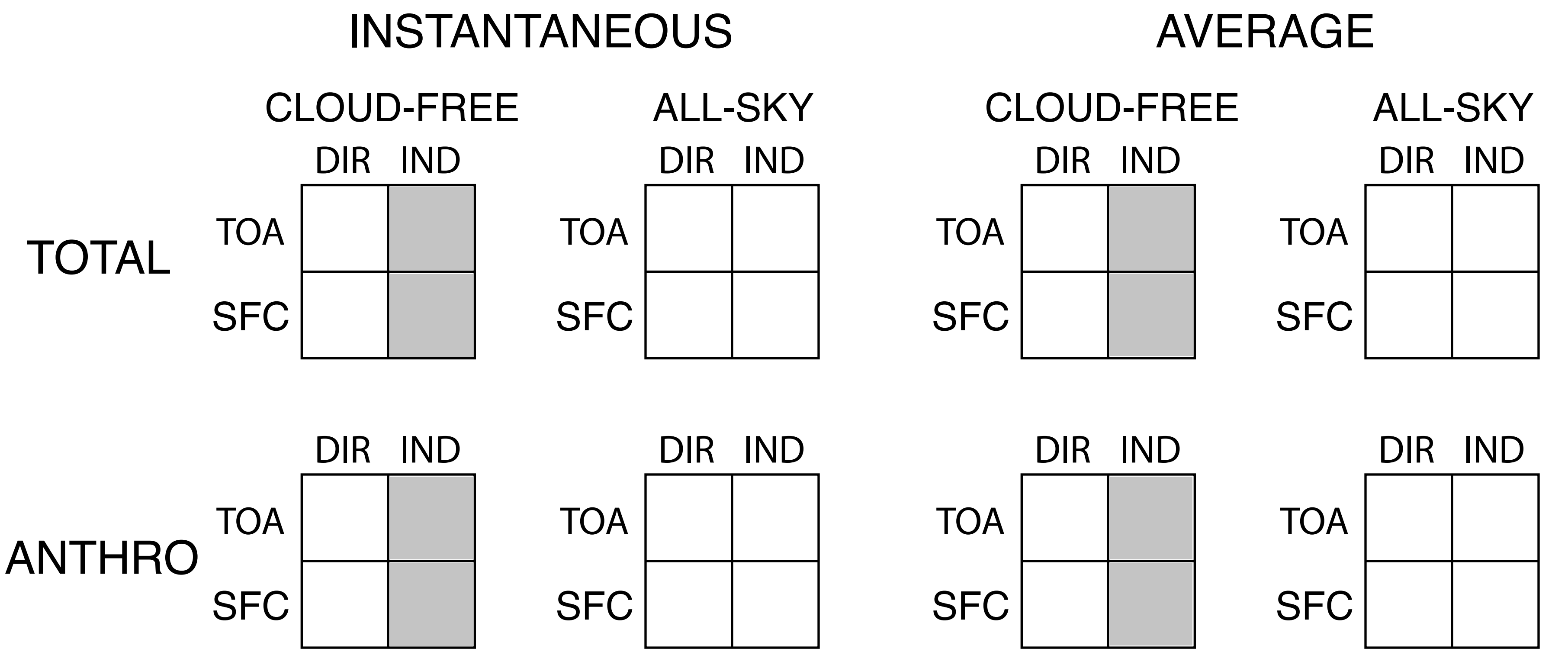
# AEROSOL FORCINGS TO BE DETERMINED




Thirty two forcings to be determined.

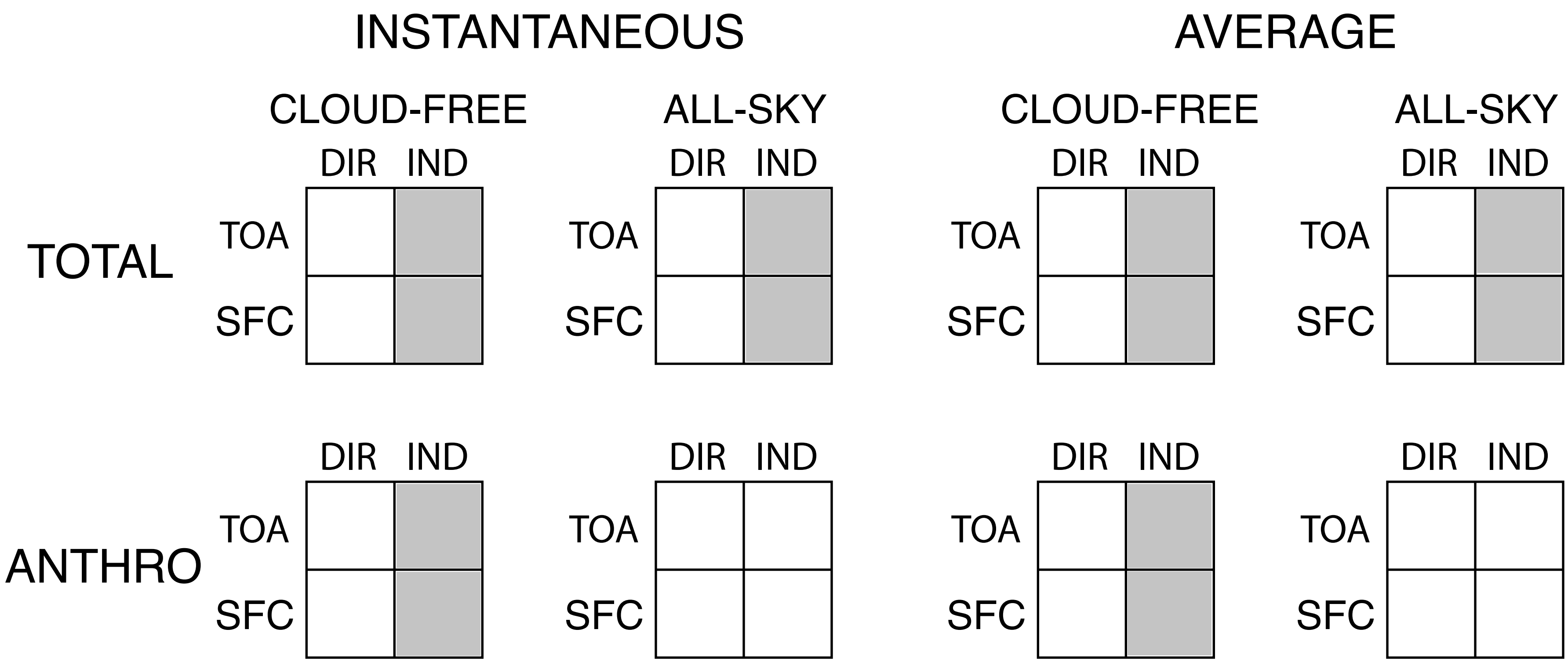
Sixty four if shortwave and longwave are determined separately.

# AEROSOL FORCINGS TO BE DETERMINED




No indirect forcing in cloud-free sky.

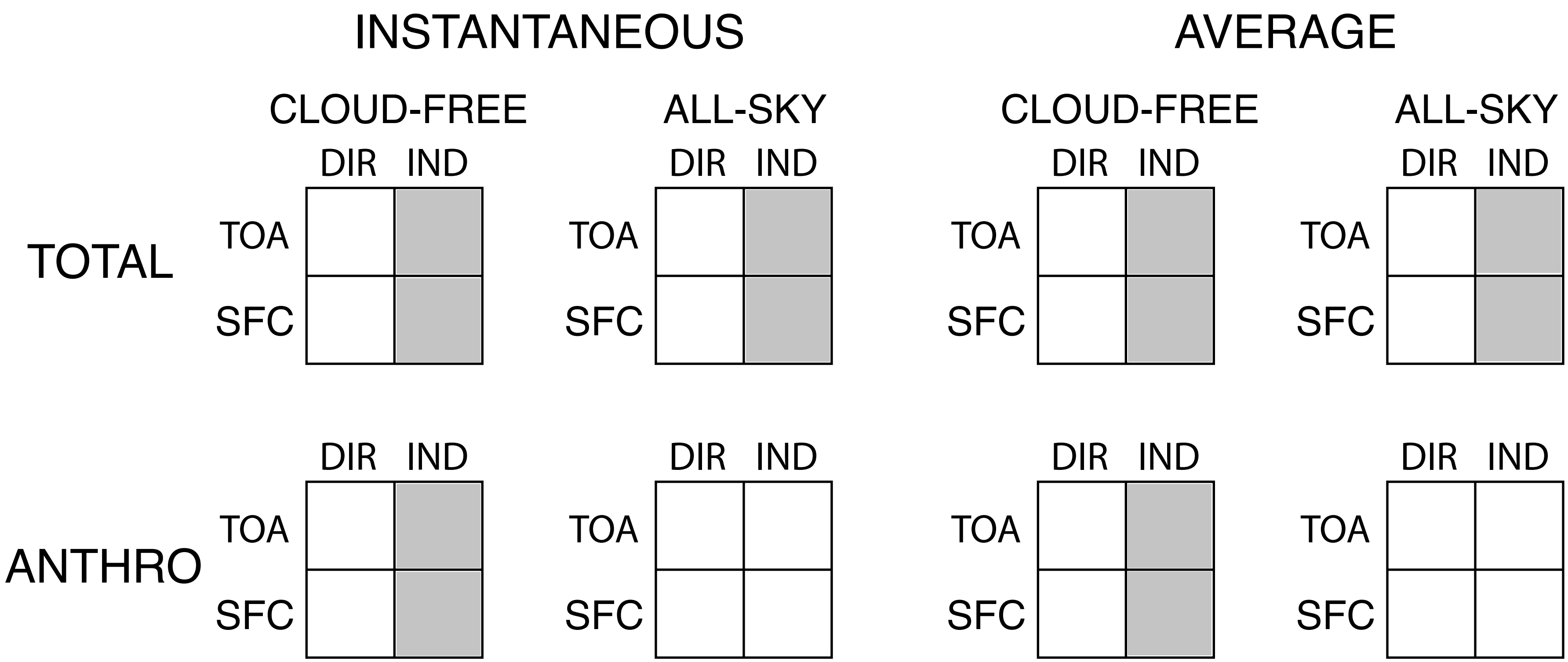
# AEROSOL FORCINGS TO BE DETERMINED




No indirect forcing in cloud-free sky.

Indirect forcing must be referred to natural aerosol, not zero aerosol.

# AEROSOL FORCINGS TO BE DETERMINED

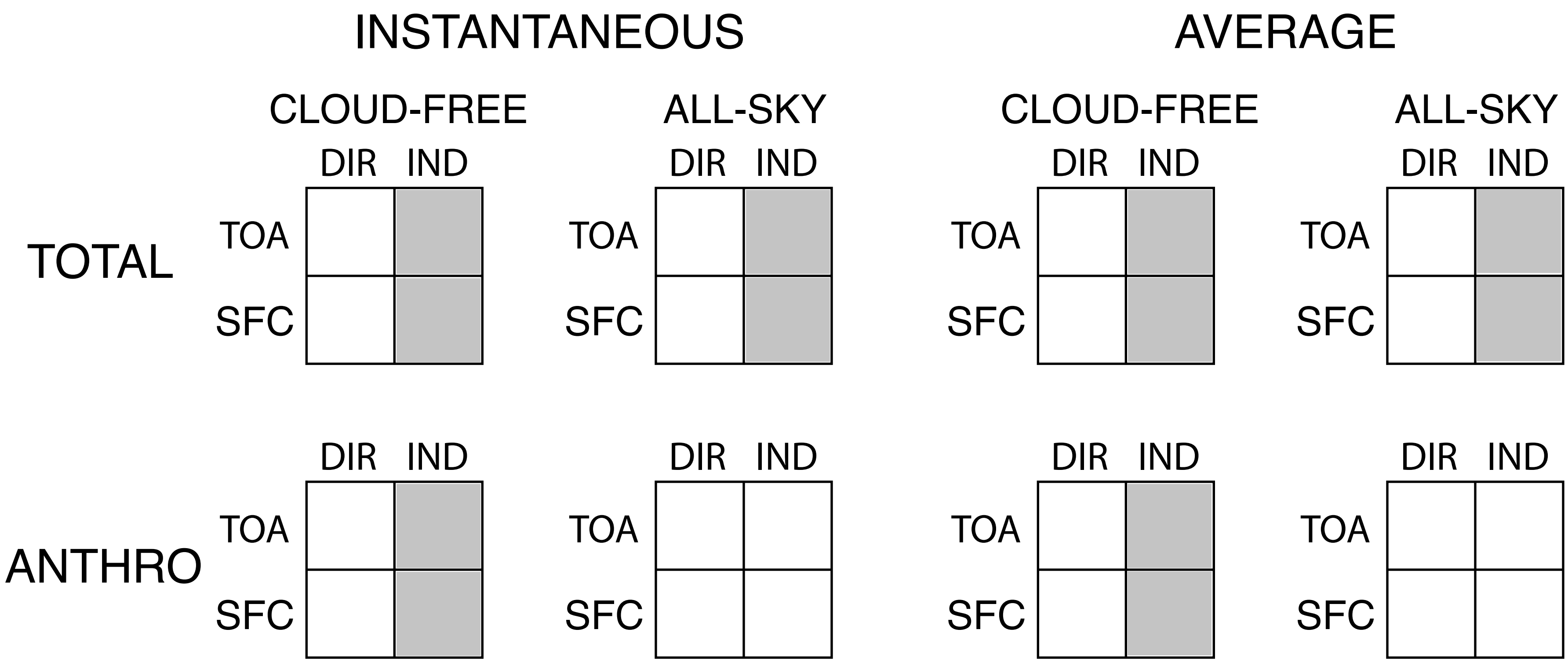



No indirect forcing in cloud-free sky.

Indirect forcing must be referred to natural aerosol, not zero aerosol.

Ten forcings to be determined, instantaneous and average.

# AEROSOL FORCINGS TO BE DETERMINED




No indirect forcing in cloud-free sky.

Indirect forcing must be referred to natural aerosol, not zero aerosol.

Ten forcings to be determined, instantaneous and average.

Twenty, if shortwave and longwave are determined separately.

# CHALLENGES IN DETERMINING AEROSOL RADIATIVE FORCINGS

Determining ***anthropogenic contribution*** to aerosol.

Aerosol mass spectrometer

Modeling

Aerosol ***optical properties*** ($\sigma_{ep}$, $\omega_0$, $g$) including RH dependence as $f(x, y, z)$.

$\boldsymbol{N_{\mathbf{ccn}}(s)}$ ***and*** $\boldsymbol{N_{\mathbf{cd}}}$ for actual and natural aerosol as $f(x, y, z)$. $s$ is supersaturation.

Determination of ***3-D cloud morphology***.

***3-D Radiative transfer calculation*** of direct and indirect forcing.

Accuracy sufficient to lend confidence to modeling of difference due to anthropogenic aerosol

***Consistency and error estimation*** from radiation measurements.